COMPARISON OF CO2 AND COST-OPTIMISED ENERGY SYSTEM FOR A RESIDENTIAL BUILDING IN GERMANY

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Overview

The issue of CO_2 emissions in residential buildings is a critical problem that requires urgent attention. This paper sheds light on the potential of fuel cell micro-combined heat and power (FC-mCHP) systems to substantially reduce CO_2 emissions in heating systems in Germany. In addition, the paper conducts simulations for various heating configurations to determine the best control strategies for reducing overall CO_2 emissions and costs.

Therefore, this paper aims at quantifying and minimising annual CO_2 emissions for heating one representative type of residential building in Germany, considering different types of heating. Six configurations of heating systems, including two types of fuel cells, a heat pump, an auxiliary gas boiler, and hybrid systems (heat pump + fuel cell and gas boiler + fuel cell), are dimensioned and simulated for a single-family house. Their control strategies are optimised towards using or generating energy when CO_2 reduction potential is highest. This shift to hours with a lower CO_2-intensive electricity mix is mainly enabled by using the thermal inertia of the buildings or the hot water storage for heat load shifting. In addition, the operation cost of the different systems is calculated. Furthermore, a comparison is made to analyse the differences between a CO_2-optimised and a cost-optimised operation.

The study provides a comprehensive understanding of the subject and can offer actionable recommendations for reducing CO_2 emissions in residential heating systems. Furthermore, it underscores the importance of taking proactive measures to reduce CO_2 emissions in all sectors, including residential heating systems, to combat climate change and achieve a sustainable future.

Methods

The methodology employed in this paper consists of three main steps. Step 1 involves the collection and pre-processing of relevant data. The reference buildings' hourly heat and electricity consumption profiles, weather and hourly electricity emissions data are obtained, as well as the energy price projections and feed-in tariffs data. All data is pre-processed to ensure its accuracy and suitability for analysis.

In Step 2, four predefined system configurations are optimised towards minimal CO_2 emissions. The configurations are an auxiliary gas boiler, a heat pump, a combination fuel cell + heat pump, and a combination fuel cell + auxiliary gas boiler. Six scenarios are analysed by considering two fuel cell technologies. The optimisation is performed using an energy system model that accounts for the energy consumption and production of the system and the electricity emissions associated with the production of the consumed electricity. The linear optimisation model aims to minimise the CO_2 emissions of each system configuration while ensuring that the building's energy demands are met.

In Step 3, the results obtained from the optimisation are evaluated based on metrics such as annual CO_2 emissions and annual gas + electricity costs. Finally, the best system configuration with minimal CO_2 emissions and the lowest costs is determined, taking into account the earnings from the sold electricity of the fuel cell.

Results

The findings suggest that using FC-mCHP systems can help to reduce CO_2 emissions in residential heating systems, making it an attractive option for homeowners and policymakers alike. Furthermore, the study quantifies the operational cost of various heating systems, providing valuable insights into the economic viability of different solutions. In Figure 1, various parameters are plotted in a heatmap over the reference year 2022 to identify their influence on each other.

Results for the single-family house scenarios can be found in Figure 2 and Figure 3. Based on the study findings, it is recommended that hybrid scenarios incorporating fuel cell and heat pump technologies should be considered for reducing CO_2 emissions in residential heating systems in Germany. The study also suggests hybrid systems demonstrated better resilience to price fluctuations than other system configurations.

Conclusions

To encourage sustainable energy practices, incentives should be provided to promote CO_2-optimized production patterns. These incentives can help to promote sector coupling of the heat and electricity sectors, thereby reducing CO_2 emissions in the heat sector and encouraging homeowners to adopt more sustainable energy practices. Finally, regarding the most effective solution for minimising CO_2 emissions, it is suggested that the hybrid system combining fuel cell and heat pump technologies would be the most suitable option.

The study recommends further research to evaluate the cost-effectiveness of the various system configurations, including CAPEX and maintenance costs. In addition, policymakers should consider implementing policies that encourage homeowners to adopt sustainable heating systems, such as those evaluated in this study, to help mitigate climate change's impact.

References

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Figure 1: Dependencies of various parameters over a year

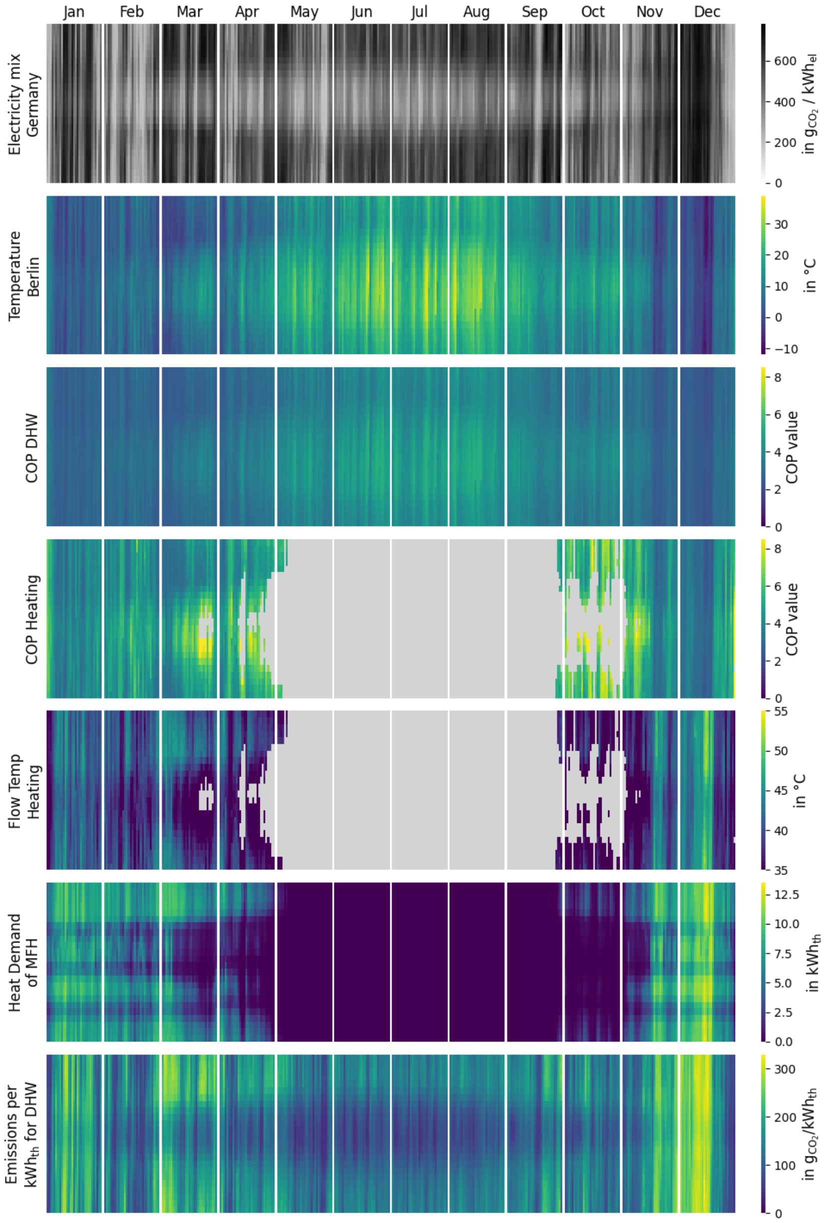

Figure 2: Composition of CO2 emissions for the six SFH scenarios in 2022

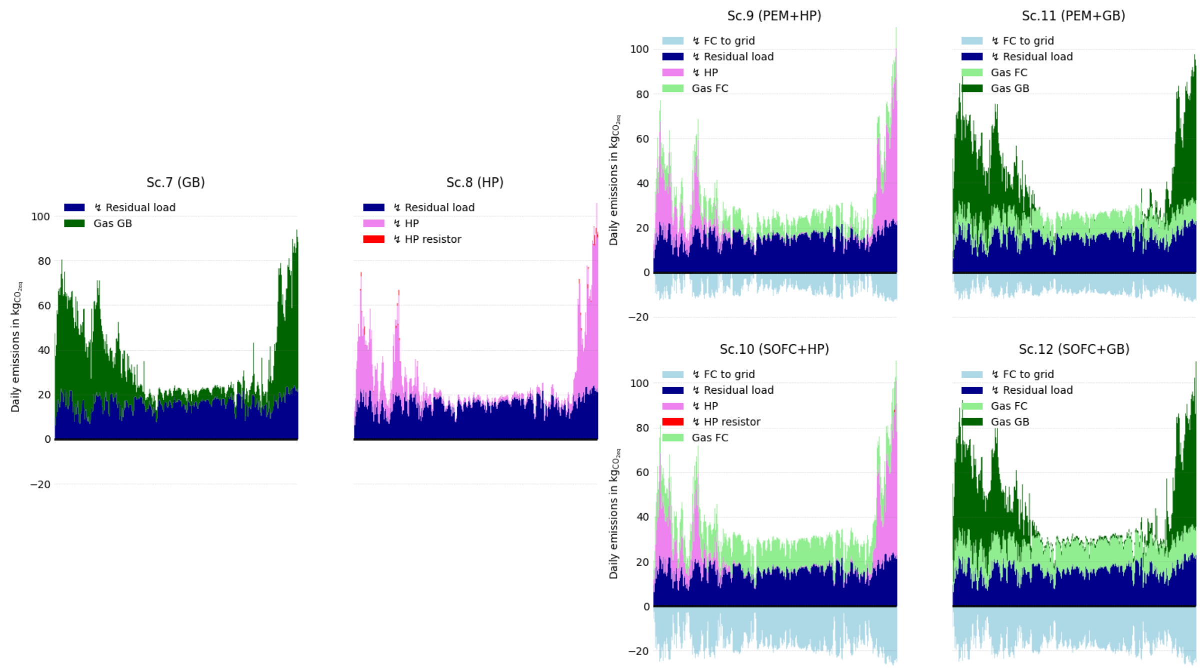

Figure 3: Comparison of the annual energy costs with annual CO2 emissions for the six scenarios of the SFH